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THE REFLECTANCE OF PAINTS AND PIGMENTS

I. INTRODUCTION

The bureau is often asked to give information on the values of reflectance for various kinds of material, including paints, pigments, papers, dyed materials, and "colors" in general. As a rule, such materials are too variable in their characteristics, or the range of colors included under a given name is too wide, to enable specific values to be given. In addition, the apparent reflectance of certain materials, for example, aluminum paint, varies over such a wide range depending on the conditions of illumination and observation, that any stated value for such materials is nearly meaningless unless those conditions are precisely specified. However, considerable information is available in the literature on the reflectance of paints and pigments, from which one can get an approximate idea of the apparent reflectance of any given sample merely by comparison with the samples and values thus published. It is the purpose of this letter circular to note these references briefly, stating the type of material illustrated and the type of reflectance measured.

1. Definitions.

In order that this information may be as specific as possible, it is necessary to define certain types of reflectance and to designate the experimental conditions used to obtain the published values.

Reflectance, R , is defined as the ratio of reflected to incident radiant energy. If measured as a function of wave length, it is called spectral reflectance and is designated as R_λ . If evaluated according to the spectral luminous-efficiency curve (the so-called visibility curve), either by direct visual measurement or by computation, it is referred to as luminous reflectance, with the symbol, R_L . Values of these quantities vary somewhat with the angular conditions of illumination, but cannot exceed unity. The type of illumination will be designated by subscript as completely diffused (D), partially or imperfectly diffused (d), or uni-directional at some specified angle, such as 45° or 0° (normal); thus, $R_{(D)}$, $R_\lambda(45)$, $R_L(0)$, etc.

However, the appearance of a paint or other surface does not usually correlate with the luminous reflectance as well as it does with another quantity designated as the apparent luminous reflectance, A_L . This term is defined as the luminous reflectance which a perfectly diffusing sample would need to have in order to yield the same brightness under the same observing conditions. Analogously, the terms, apparent reflectance, A , and apparent spectral reflectance, A_λ , may be defined. Values of these three types of apparent reflectance may vary widely depending both on the angular distribution of the incident light

and the angle at which the reflected light is observed, and such variations are much greater for glossy than for matt surfaces, often exceeding unity for the former. Subscripts in parentheses designate, first the character of the illumination, and second the angle of observation of the reflected light, thus:

$A_L(D, 0)$ is the value of A_L obtained with completely diffused illumination, the reflected light being taken at right angles to the surface.

$A_L(d, 0)$ represents the similar quantity measured with illumination which is not completely diffused.

$A(45, 0)$ is the value of A obtained with a uni-directional beam incident upon the sample at 45° , the reflected light being taken at right angles to the surface. These conditions are recommended by the International Commission on Illumination.

$A_\lambda(0, 45)$ represents the value of A_λ under the converse conditions of normal illumination and 45° observation.

From the Helmholtz reciprocal relation ⁽¹⁾ the following important equivalents may be noted:

(1) H. J. McNicholas, Absolute Methods in Reflectometry, BS J. Research 1, 29 (1928); RP 3.

$A_L(D, 0)$ is numerically equal to $R_L(0)$. A similar equivalence holds between $A_\lambda(D, 0)$ and $R_\lambda(0)$ and between $A(D, 0)$ and $R(0)$. This relation is valid also for any angle other than 0° .

$A_L(45, 0)$ is numerically equal to $A_L(0, 45)$, $A_\lambda(45, 0)$ to $A_\lambda(0, 45)$, and $A(45, 0)$ to $A(0, 45)$. This relation also holds for angles other than 0° and 45° .

2. Reference Standards of Reflectance.

Most of the values of R_L , A_L , and A_λ given in the references below are dependent on the value assigned to, or were obtained and are given relative to, some reference standard of reflectance. In many cases this standard of reference is magnesium carbonate ($MgCO_3$). Fresh samples of this material may have a value of R_L as high as 0.98; however, the value of R_L is occasionally less than this, possibly as low as 0.90, due to deterioration with usage or to impurities originally present in the material. Values of reflectance may, therefore, be subject to some uncertainty when $MgCO_3$ has been used as a reference standard.

More recently magnesium oxide (MgO) has come into use as a standard of reflectance. It is apparently very reproducible in its reflecting properties when properly prepared; it has a value of R_L equal to approximately 0.97 and values of $A_L(45, 0)$ and $A_L(0, 45)$ equal to approximately 1.00; and it varies in its reflectance by less than one per cent throughout the visible spect-

rum. The method of preparation of such a standard of reference, together with references to publications on the subject, is given in letter circular, LC-395, of the National Bureau of Standards.

II. PUBLICATIONS GIVING THE REFLECTANCES OF VARIOUS CHROMATIC SAMPLES.

1. H. A. Gardner, The Light-Reflecting Values of White and Colored Paints, J. Frank. Inst., 181, 99 (1916). Gives values of $R_L(45)$, in per cent, on a scale giving a value of 88% for $MgCO_3$, for 16 illustrated matt samples of colored wall paints, "made on a mixed white pigment base, tinted with chrome yellow, chrome green, prussian blue, para red, ochre sienna, carbon black, etc." The illuminant used was incandescent light.

2. M. Luckiesh, The Physical Basis of Color-Technology, J. Frank. Inst., 184, 73 (1917). Angular conditions of illumination not stated but specular reflectance apparently excluded from the measurements. Reference standard of reflectance not stated. Values of A_λ (tables and curves) are given from 440 m μ (blue-violet) to 720 m μ (extreme red) for the following dry, powdered pigments: American vermillion, venetian red, tuscan red, indian red, burnt sienna, raw sienna, golden ochre, chrome yellow ochre, yellow ochre, chrome yellow (medium), chrome yellow (light), chrome green (light), chrome green (medium), cobalt blue, and ultramarine blue. Computed values of A_L for these pigments are also given for noon-sun, blue-sky, and tungsten-filament illuminants, illustrating the variation in the values of A_L with illuminants of different color, which occurs in general for chromatic materials.

3. G. F. A. Stutz, Observations of Spectrophotometric Measurements of Paint Vehicles and Pigments in the Ultra-violet, J. Frank. Inst., 200, 87 (1925). Values of $A_\lambda(45,0)$ are given (Tables II and III) at eight wave lengths of the mercury-arc spectrum from 546.1 m μ (yellowish green) to 253.6 m μ (ultra-violet) for 18 "white pigments-inerts" and for 38 "colored pigments". Several graphs are also given showing similar values for various mixtures of certain pigments. The value of $A_\lambda(45,0)$ for MgO is given as 0.98 on the scale used.

4. H. D. Bruce, Tinting Strength of Pigments, BS J. Research 1, 125 (1928); RP 7. Curves are given showing values of $A_\lambda(d,0)$ from 430 m μ (blue-violet) to 700 m μ (extreme red) for oil pastes of various pigments designated as medium chrome yellow, dark chrome yellow B, prussian blue, chrome green, red lead, dark chrome yellow, greenish chrome yellow, and para red, and for various mixtures of each of these with a zinc oxide paste. The samples were "measured under glass slides", and the values are given relative to $MgCO_3$ and in per cent. Values of $A_L(d,0)$ for noon sunlight are also given for the various pastes and mixtures, derived from the spectrophotometric data and applying to the same experimental conditions.

5. Munsell Book of Color, Munsell Color Company, Inc., Baltimore, Md., 1929. On page 42 of this book are given values of "reflection factor" (probably $A_L(45,0)$), in per cent, equivalent to Munsell "values" from 0.0 to 10.0. The illuminant used was artificial noon sunlight and the values were obtained relative to MgO. By reference to this table one can estimate the value of $A_L(45,0)$ for any sample which can be matched in color by, or is intermediate in color between, any of the approximately 400 painted paper samples in the Munsell Book of Color. The Munsell papers are nearly matt.

6. Illumination Design Data for Industrial and Commercial Interiors, L.D.-6, issued by General Electric Company, Nela Park Engineering Department, Cleveland, Ohio, 1930. Values designated as "reflection factors for light from Mazda lamps" (probably values of $R_L(40)$), in per cent, are given for 6 "ceiling tints", 10 "side wall tints", 3 "dado paints", 2 "natural finishes", 4 "wood finishes", and 7 "wall papers". These samples are all illustrated, with holes punched to facilitate comparison. A revised copy of this publication is to be issued during 1936.

7. British Standard Schedule of Colours for Ready-Mixed Paints, issued by the British Engineering Standards Association, 1930. In Appendix II, pp. 56 and 57, are given values of $A_L(45,0)$, relative to MgO and in per cent, for 64 illustrated samples of paint mounted under transparent celluloid. The values are designated as "Shade". The illuminant used was artificial noon sunlight. The accepted British names for these colors are also given.

8. The Light Reflection Value of Color in Paint, issued by the New Jersey Zinc Company, 160 Front Street, New York, N. Y., 1931. In Part 2 is given a chart showing values of $A_L(0,45)$, in per cent, for (1) a series of grayish, reddish, yellowish, greenish, and bluish samples, nearly matt, arranged in order of Munsell "value" from 1 to 8, and (2) a selection of 16 "paint colors selected for their adaptability to industrial use", including one sample of "aluminum gray". The illuminant used is not stated, nor the reference standard of reflectance.

9. Artificial Light and Its Application in The Home, prepared by the Committee on Residence Lighting of Illuminating Engineering Society, published by McGraw-Hill Book Company, Inc., New York, 1932. Between pages 20 and 21 are given values designated as "reflection factors of colored surfaces" (probably values of $R_L(40)$), in per cent, for 32 painted samples, some glossy, some nearly matt. The illuminant used was light from a tungsten-filament incandescent lamp.

10. Circular No. 486, entitled, Reflection Values, issued by the Scientific Section, National Paint, Varnish and Lacquer Association, Inc., 1935. Values of $A_L(0,45)$, relative to MgO and in per cent, are given for 42 illustrated paint samples -- 24 "gloss house paints", 17 "flat wall paints", and 1 aluminum paint. The illuminant used was artificial noon sunlight.

As an example of the use of the information given in the above publications, the apparent luminous reflectance of the yellowish paint on the wall of one of the rooms of the bureau was estimated by comparison with the samples illustrated in the circular of reference 10, above. While not matching any of the samples perfectly in color, it was obvious that the wall was slightly lighter than "No. 4F-56%", definitely darker than "No. 3F-66%", and closely like "No. 1F-59%". It was, therefore, concluded that the apparent luminous reflectance of the painted wall was about 60%.

In the case of a green desk blotter, the color was found to be intermediate between "No. 17G-32%" and "No. 18F-7.9%", appearing roughly half-way between. Since the lightness of a sample is approximately proportional to the logarithm of its apparent luminous reflectance, the value of A_L for the blotter is obtained from the relation, $\log A_L = 1/2 (\log 32 + \log 8)$. A value of A_L equal to 16% is thus obtained, which is perhaps the best estimate one could make with such a large interpolation. A closer estimate was obtained by comparison with the samples in the Munsell Book of Color. The blotter was found to match the "green-yellow green" colors best and to be intermediate between "GY-G 4/4" and "GY-G 5/4", slightly closer to the former. Its Munsell "value" is, therefore, approximately 4.4. Reference to the table on page 42 of the Book of Color shows that this Munsell "value" is equivalent to an apparent luminous reflectance of about 13% -- as against the 16% inferred above.

III. THE REFLECTANCE OF WHITE PAINT AND ALUMINUM PAINT.

There seems to be some difference of opinion as to whether white paint or aluminum paint has the greater "reflection value" and, indeed, there is considerable uncertainty as to the proper value to assign to aluminum paint. The confusion is doubtless due to the fact that the reflection term or value is often used without exact definition. As already stated, values of A_L for aluminum paint vary over a wide range, much more so under ordinary viewing conditions than do any of the glossy white paints. The following values are considered fairly representative of white and aluminum paints:

Quantity	Kind of Paint	Value
$A_L(D, 0) = R_L(0)$	Aluminum	0.63 to 0.68 ⁽¹⁾
	Outside white }	{ (About the same as ($A_L(0, 45)$)).
	Inside white }	
$A_L(0, 45) = A_L(45, 0)$	Aluminum	0.18 to 0.42
	Outside white	0.75 to 0.80 ⁽²⁾
	Inside white	0.84 to 0.92 ⁽²⁾

$A_L(45, -45)$	Aluminum	Greatly exceeding unity (3)
	Outside white	{ For glossy paints, greatly exceeding unity (3)
	Inside white	{ For nearly matt paints, somewhat greater than $A_L(0, 45)$

(1) Aluminum metal may have values from about 0.31 (ground surface) to about 0.85 (freshly etched, $R_L(40)$). See papers by A. H. Taylor and J. D. Edwards, Ultra-violet and Light Reflecting Properties of Aluminum, J.O.S.A., 21, 677, Table 2, (1931); and by H. J. McNicholas, Absolute Methods in Reflectometry, BS J. Research 1, 29, Fig. 5 and Table 3, (1928); RP 3.

(2) Glossy paints will have values slightly lower (usually from 2 to 4 per cent) than nearly matt paints of similar kind.

(3) The values obtained depend very importantly on the angular apertures of the incident and receptor beams, increasing enormously as the apertures become very small. For fairly large apertures, the value of $A_L(45, -45)$ will be greater for aluminum paint than for glossy white paint; for very small apertures the glossy white paint will have the greater value.